research review

OAR: The Research Agency
of The United States Air Force

VOLUME III NUMBER 5 JULY 1964

THE RADIATION BELTS: A CLOSER INSPECTION

LUDWIG KATZ, Space Physics Laboratory, AFCRL

The first U.S. satellites told us that the earth is surrounded by a belt of high-energy particles. With our first deep space probe, we learned that we are surrounded not by one such radiation belt, but by an inner belt and an outer belt. Still later, this neat little packet of knowledge became somewhat obscured because subsequent measurements indicated that there may not be two belts after all, but one continuous zone of radiation.

Actually, both views of this Van Allen radiation are valid. It depends on the energies of the particles being measured. If we measure particles at one energy level and plot a distribution curve of the number of particles at given distances from the earth, we find that the curve describes two peaks with a deep valley between, clearly a portrait of two belts. But at another energy regime, we find a single peak, with a uniform decrease as we move outward toward the higher L-shells (that is, towards the outer magnetic lines of force of the earth).

This picture of Van Allen radiation has come into much sharper focus with the release of data obtained by an AFCRL satellite launched on 1 July 1963. Instrumentation aboard this satellite has permitted us to define the structure of the Van Allen belt with a higher resolution and greater detail than that of any previous satellite. The AFCRL satellite has uncovered several previously unknown features of the belt.

The 176-pound satellite was launched as a hitchhiker aboard a larger Air Force satellite. Four days after launch, the AFCRL satellite was separated from the primary satellite and kicked into its own separate orbit. The polar orbit with a perigee of 210 miles and an apogee of about 2560 miles permitted the satellite to pass through a good cross section of the Van Allen belt.

In the AFCRL measurements, the count rate for protons between one and five million electron volts (Mev) indicated that, for this energy region, there are in fact two distinct belts. The count was significantly lower in the middle region between the two belts. Hitherto, many scientists have believed that protons at energies between one and five Mev were restricted to the inner zone with a gradual fade-off with increasing distance from the earth.

A second feature uncovered in measurements between 15 and 100 Kev was that more electrons are found in the energy region of 40 Kev than at any other energy level. This

prevalence of 40-Kev electrons is not dependent on a particular region of the radiation belt, although there is a decrease in total flux of electrons from the inner to the outer L-shells. AFCRL data show, for example, that there are about 10 times as many particles at 40 Kev than at 20 Kev.

These low-energy electrons are not a serious hazard to man in space. But over a period of time, they could affect the performance of electronic equipment carried aboard the satellite. They are also of interest because there are so many more of them than the high-energy particles. AFCRL, through its study of Van Allen radiation, hopes to obtain more precise information on such questions as the source of the particles, their direction, and trapping and removal mechanisms.

Solar activity, cosmic rays, and atmospheric nuclear detonations all affect the character of the Van Allen belt. Therefore, the structure changes, and a definition of the structure at one point in time may not hold true at another time.

The instrumentation for the AFCRL satellite was developed by American Science and Engineering, Inc. It includes six types of instruments: a proton detector, plasma probe, electron detector, electrostatic analyzers, geiger counter and magnetometers. With this instrumentation, energy differences to better than 15 per cent were resolved. It permitted many measurements to be made simultaneously, and it also measured the direction of travel of the particles.

All the hitchhiker's instruments functioned throughout the satellite's lifetime of three months. Tape-recorded data obtained between 1 July and 7 September 1963 gave a total of more than 100 orbits from which experimental data are now available for analysis. Preliminary analysis has been made of only a few orbits. It will be some time before all the data have been reduced and analyzed.

research review
OFFICE OF AEROSPACE RESEARCH

THE RADIATION BELTS: A CLOSER INSPECTION
Ludwig Katz 1

GEOLOGY OF THE TERRESTRIAL PLANETS
Terrestrial Sciences Laboratory 3

EVIDENCE FOR A NEW CRYSTAL PHASE OF ZIRCONIA
Dr. Robert Ruh 4

A METHOD OF CALCULATING POWER REQUIRED FOR A HYPERSONIC WIND TUNNEL
Anthony W. Fiore 6

"PROHIBITION" FOR WIND-TUNNEL PEBBLE BEDS
Robert G. Dunn 13

STUDIES OF THE THERMODYNAMICS OF ALLOY FORMATION
Lawrence R. Bidwell 14

TRANSIENT ROTATION OF CONFINED VISCOUS FLUIDS
Major B. R. Agins 16

DISCOVERING THE INVARIANT CHARACTERISTICS OF THINGS
Charlton M. Walter 17

"BRIDGING THE GAP" BETWEEN THEORY AND PRACTICE IN CONTROL THEORY
Major Bernard S. Morgan, Jr. 18

PRECURSOR ARCS IN ELECTRIC SHOCK TUBES
Dr. Robert F. Stetson 19

WHEN IS A MATHEMATICIAN A MATHEMATICIAN?
Captain John F. Gander 20

OAR RESEARCH REVIEW is published monthly by the Office of Scientific and Technical Information (RRYC), Hq Office of Aerospace Research, USAF, 4th and Independence Avenue, S.W., Washington, D. C. 20333. The objective of this publication is to make a positive contribution to the exchange of information concerning Air Force conducted and sponsored research activities. Individuals or organizations interested in or associated with research may obtain copies without charge by written request to the above address.

JACOB SEIDEN
Editor

OARRP 80-1

esearch review
ICE OF AEROSPACE RESEARCH

CHANGE ADDRESS?
SEND THIS NOTICE TODAY
No postage required if mailed in the United States.

TYPE OR PRINT NEW ADDRESS HERE

ATTACH LABEL HERE

Paste here old address label from copy of publication or facsimile

NAME _____

COMPANY _____

DIVISION _____

COMPANY ADDRESS _____

CITY _____ STATE _____ ZIP CODE _____

OAR (RRYC)
BLDG T-D
WASH DC 20333

UNITED STATES AIR FORCE
OFFICIAL BUSINESS

POSTAGE AND FEES PAID
DEPARTMENT OF THE AIR FORCE

OAR (RRYC)
BLDG T-D
WASH DC 20333

geology of the terrestrial PLANETS

Terrestrial Sciences Laboratory, AFCRL

The long, narrow strips of outcropping Paleozoic rock found in northwest Africa at the edge of the Sahara might very well be described by an observer on Mars as canals on the earth. From a TIROS satellite, they look like canals. If we look at the desert regions of Central Asia from a satellite, and compare these with our telescopic observations of the Martian deserts, we see great similarity.

These facts suggest that the study of photographs of the earth taken from balloons, rockets and satellites might be of great help in interpreting the geological features not only of Mars, but also of Mercury. A comparative study of satellite photography of the earth and other planets may lead to certain plausible hypotheses of the surface and atmospheric features of Mercury, Venus, and Mars. Such a comparative study is being conducted at AFCRL by J. F. Cronin and Lt. James Neal. The study is concerned primarily with photographs taken in the visible region. However, as more and more infrared photographs are taken from satellites and ground observatories, they should augment the study.

Part of the study, which is still in the preliminary stage, involves an important assumption. This assumption is that Mercury, Venus, Earth and Mars started off with similar atmospheres. The atmospheres of each of the planets are now, of course, distinctly different. These differences are the result of evolutionary change. The earth's atmosphere, although relatively stable for millions of years, underwent great changes during its early history. Similar changes, on a different time scale, may have occurred on other planets.

With the assumption of initial similarities, then, the interpretation of the photographs depends on certain kinds of knowledge. We must first understand the atmospheric and hydrospheric processes which bring about oxidation, weathering, erosion and sedimentation, and which in turn change geologic features. Next, the comparative interpretation of photographs requires a knowledge of the earth's geological development. Such knowledge will not only help us to interpret the features of the planets, but the evolution of these surface features as well.

In their paper, Cronin and Neal devote most of their discussion to geological comparisons of Earth and Mars. This is because we have a chronology of Martian seasonal changes and meteorological events dating back to the early 1900's. An example of a meteorological event was a cloud front that was observed on August 29 and 30, 1956 and which moved across the southern hemisphere of Mars. After the cloud front passed, it left in its wake a large darkened region which persisted for a day or two. An outstanding comparative example of this darkening following precipitation was observed by a TIROS satellite in the west African desert region. Because of the similarity, it is possible to speculate that light precipitation did in fact occur on Mars and that the rain fell on a surface of fine-grained silt or dust. Such material, when moistened on Earth, will produce a lowering of albedo comparable to that observed on Mars.

The use of infrared photography of the earth and of Mars, Mercury and Venus may furnish many additional clues to the historical geology and atmospheres of the earth's immediate neighbors. It is not necessary that the photographs of the earth be obtained by satellite. Rockets and balloons can carry cameras aloft to obtain photographs of earth features for comparison. ★

evidence for a new crystal phase of ZIRCONIA

Dr. ROBERT RUH, Metallurgy and Ceramics Research Laboratory, ARL

Zirconia has excellent potential as a high-temperature material because it has an extremely high melting point (2680°C), high chemical stability, and it is inexpensive and readily available commercially. However, its polymorphy, or occurrence in different crystal structures, is probably more complex than that of any other refractory oxide and is still not completely understood. As a result of this, its usefulness is limited. At room temperature, the pure material exists in a monoclinic crystal structure which inverts to a tetragonal structure at approximately 1100°C. This inversion is accompanied by a large change in volume which causes cracking and disintegration upon cooling and renders the pure material structurally useless. The destructive inversion can be eliminated by the addition of foreign oxides which "stabilize" the material in a cubic or tetragonal crystal structure. Although stabilized zirconia maintains its structural integrity with thermal cycling, its use is limited because of poor thermal-shock resistance of the tetragonal and cubic phases. In contrast, the monoclinic phase has very good thermal-shock resistance. Recently, a second inversion has been reported in pure zirconia at 2285°C.[1] At this temperature, the tetragonal phase reportedly transforms to a cubic phase. However, this work is very recent and the characteristics of this phase and the effects of the inversion have not been determined.

In order to better realize the potential of zirconia as a refractory material, research on its polymorphy is currently being conducted at ARL. It is believed that a better fundamental understanding of the structures and inversions will make improved zirconia materials possible. Results of this work indicate that there is another transformation in zirconia between 1500 and 1475°C. Evidence for this structural change was obtained from metallographic studies of the microstructure of high-zirconia compositions in the ZrO_2-Zr system. Specimens of these compositions were fired in the temperature range 2000-1200°C until equilibrium was obtained, quenched, and observed under the microscope. Results revealed that striations of α-Zr were formed in samples quenched from 1500°C and higher temperatures, as illustrated in Fig. 1. In this figure, the striations are seen as white lines and the ZrO_2 phase as the continuous gray phase. It was further observed that the character of the striations was the same as long as the quenching temperature was 1500°C or more. The character was also found to be independent of composition. When samples were quenched from 1475°C and below no striations were formed, but rather the metallic phase was present in spherical particles as illustrated in Fig. 2. These particles have assumed a low-energy configuration, indicating that they were present at the firing temperature. All of the data indicate that the striations are formed at a fixed temperature on quenching as the result of a sharp decrease in the solubility of α-Zr in ZrO_2. This change in solubility is attributed to a new-phase inversion in the zirconia. The very existence of the striations supports this view, since they are known to be associated with a diffusionless-type transformation. Samples have been examined by high-temperature X-ray analysis, and preliminary results indicate that the new phase is a second tetragonal structure.

Another phase of this work was the determination of the ZrO_2 planes on which the Zr precipitates. This was accomplished by growing a single crystal of striated zirconia and examining it by X-ray analysis using a single-crystal orienter. Results of this work have revealed that the striations are oriented with the 111 and $11\bar{1}$ planes of the ZrO_2. These results are similar to those obtained in known diffusionless inversions and give further evidence that the new inversion is of this type. ★

[1] *Smith, D. K. and C. R. Cline, "Verification of Existence of Cubic Zirconia at High Temperatures," J. Am. Ceram. Soc., 45, (5) 249-50, 1962.*

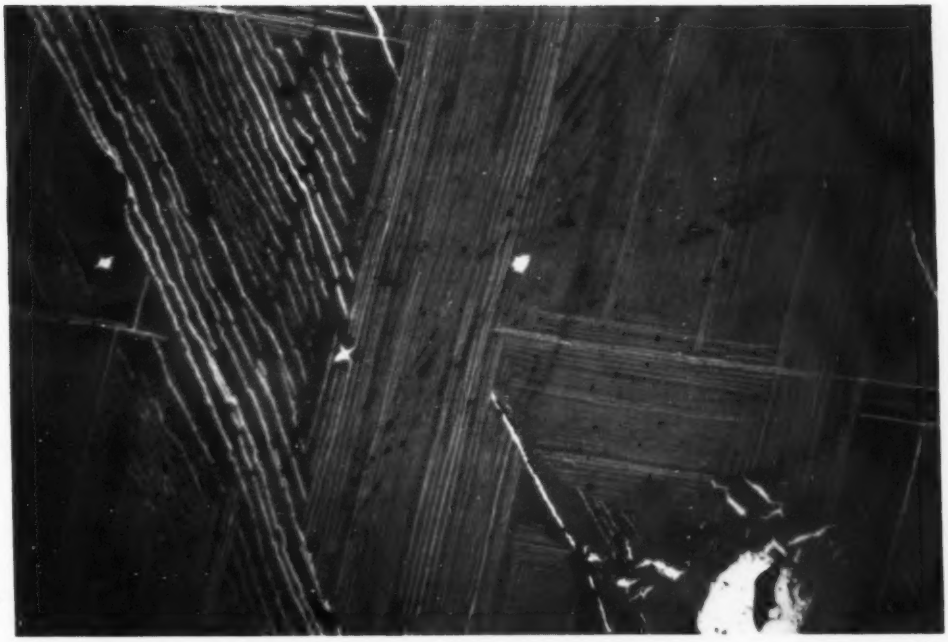


Fig 1. Equilibrated and quenched from 1500°C.

The Microstructures of a ZrO_2-Zr Composition at 400 X.

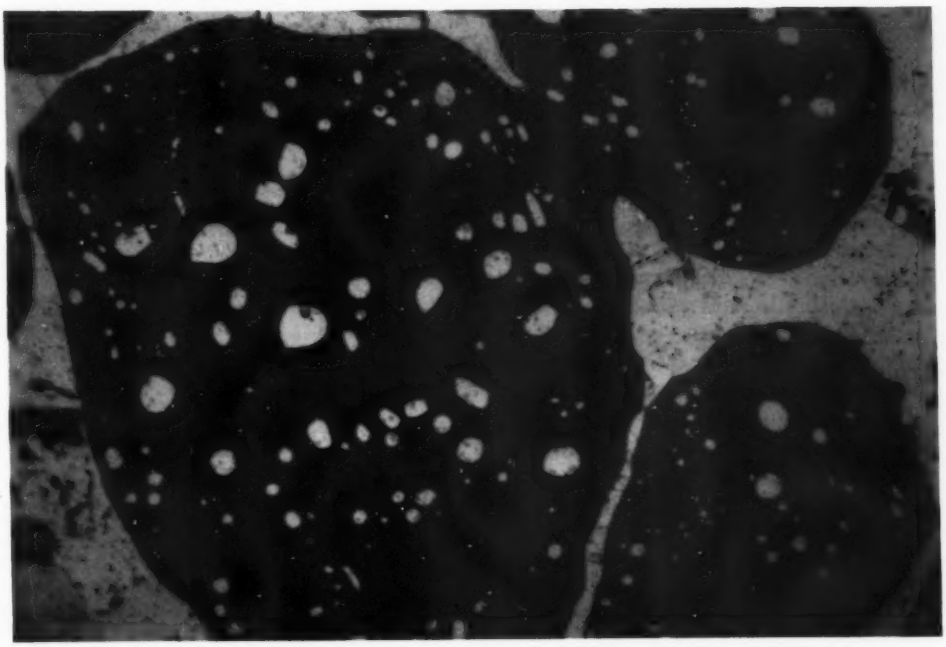


Fig 2. Equilibrated and quenched from 1475°C.

a method of calculating power required for a hypersonic *wind tunnel*

ANTHONY W. FIORE
Hypersonic Research Laboratory, ARL

In the Aerospace Research Laboratories there exist a number of hypersonic wind tunnels which are capable of producing Mach numbers from 10 to 21 at altitudes extending from 100,000 to approximately 500,000 feet. These facilities are equipped with heaters which operate at stagnation temperatures sufficiently high to avoid air liquefaction at the above-mentioned conditions. The purpose of this note is to indicate the proper mathematical equation for computing the heater power required for these facilities as a function of the stagnation pressure, the stagnation temperature, and the nozzle-throat cross-sectional area.

In order to indicate the problem involved, it is necessary first to consider the case of a hypersonic wind tunnel designed for operation in the Mach-number range of 5 to approximately 8. In this speed range, the stagnation temperature required to avoid air liquefaction varies from approximately 500°R to 1000°R depending upon the value of the stagnation pressure. Under these conditions the air temperature in the heater is relatively low; therefore, the nitrogen and oxygen molecules contain only five degrees of freedom. Three degrees of freedom are in the translational mode; and since these molecules are diatomic in nature, it is assumed that they contain only two degrees of freedom in the rotational mode. The third degree of freedom about the internuclear axis can be neglected in view of the fact that the moment of inertia about this axis is small compared to the moments of inertia about the remaining two axes. Under these conditions the ratio of specific heats and the specific heat at constant pressure may be taken as constants; their values being $\gamma_p = 1.4$ and $C_p = 5997$ ft^2/sec^2 °R respectively. Assuming air acts as a perfect gas, the power required per unit time ($\dot{Q}_r$) in kilowatts is the product of the mass flow per unit time passing through the nozzle throat ($\dot{m}$) and the enthalpy change across the heater (Δh), or

$$\dot{Q}_r = 1.356 \times 10^{-3}\, \dot{m}(\Delta h); \qquad (1)$$

the mass flow per unit time becomes

$$\dot{m} = \left(\frac{2}{\gamma_p + 1}\right)^{\frac{\gamma_p + 1}{2(\gamma_p - 1)}} A_* P_o \sqrt{\frac{\gamma_p}{R T_o}} \qquad (2)$$

where A_* = nozzle-throat cross-sectional area in square inches.

P_o = stagnation pressure in psia.

R = gas constant for air, 1715 ft^2/sec^2 °R.

T_o = stagnation temperature in degrees Rankine.

The enthalpy change across the heater can be expressed as

$$\Delta h = C_p \int_{T_i}^{T_o} dT = C_p(T_o - T_i), \qquad (3)$$

it is assumed that the air enters the heater at a temperature "T_i" and leaves the heater at the stagnation temperature "T_o." Substitution of Eqs. (2) and (3) into Eq. (1) yields the power equation.

$$\frac{\dot{Q}_r}{P_o A_*} = \frac{C_1}{\sqrt{T_o}} (T_o - T_i) \qquad (4)$$

where the constant C_1 is

$$C_1 = 1.356 \times 10^{-3} C_p \sqrt{\frac{\gamma_p}{R}} \left(\frac{2}{\gamma_p + 1}\right)^{\frac{\gamma_p + 1}{2(\gamma_p - 1)}} \qquad (5)$$

Equation (3) is presented inFigure 2 for a constant heater-inlet temperature of 510°R while Eq. (4) is plotted in Figure 3 for the same heater-inlet temperature. In both figures these curves appear as a dashed line.

Next, it becomes necessary to consider the case where a hypersonic wind tunnel is operating in the Mach-number range 10 to 21, and the heat required to circumvent liquefaction is much higher. In the derivation of the power required for this specific case, the following assumptions are made:

(1) The heater capsule is thermally insulated, so the heating takes place adiabatically,

(2) The predried air is delivered to the heater at an air-inlet temperature of "T_i" and the outlet air is at the stagnation temperature "T_o,"

(3) The temperature within the heater is sufficiently high to excite the vibrational degree of freedom of the nitrogen and possibly the oxygen molecules (caloric imperfection),

(4) The air acts as a perfect gas (thermally perfect),

(5) The conservation of mass per unit time through the heater and the nozzle throat prevails.

The power required in kilowatts is also expressed by Eq. (1). However, the mass flow through the nozzle throat now becomes

$$\dot{m} = \frac{A_*}{\sqrt{R}} \left(\frac{2}{\gamma_p + 1}\right)^{\frac{\gamma_p + 1}{2(\gamma_p - 1)}} P_o f(T_o). \tag{6}$$

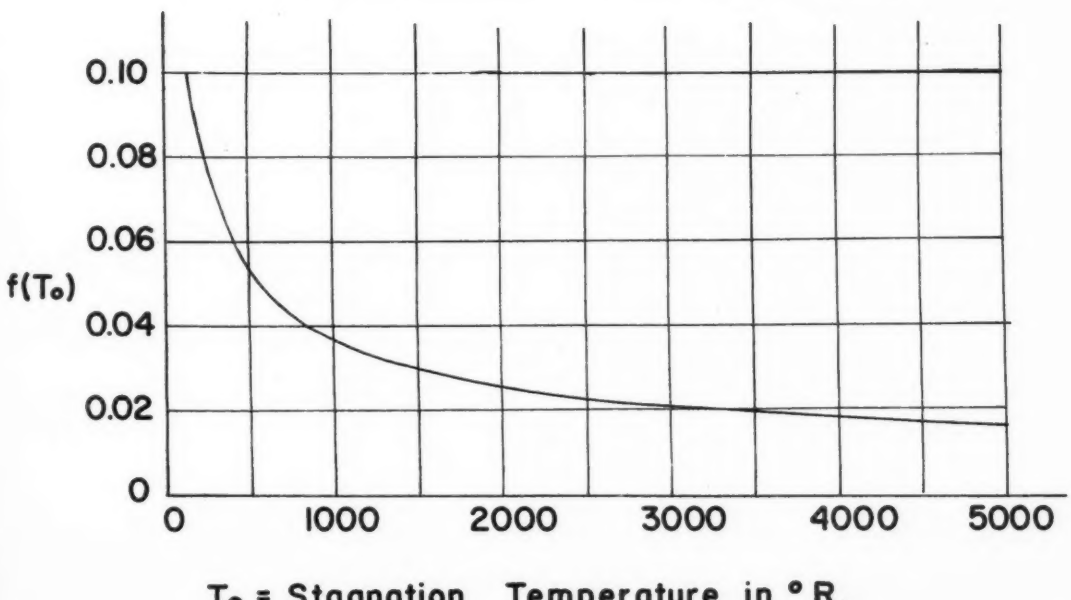
The function $f(T_o)$ is the correction factor for the vibrational degree of freedom in the specific heat ratio of the air at the nozzle-throat location and is shown in Figure 1. It can be seen by comparing Eq. (2) to Eq. (6) that, when the vibrational degree of freedom is neglected, this function reduces to the form

$$f(T_o) = \sqrt{\frac{\gamma_p}{T_o}} \tag{7}$$

The change in enthalpy across the heater for this case becomes

$$\Delta h = \int_{T_i}^{T_o} C_p(T)\, dT \tag{8}$$

Fig 1. – $f(T_o)$ Versus T_o in Deg. Rankine



where $C_p(T)$ is the specific heat at constant pressure and was obtained from both quantum mechanics and statistical thermodynamic theoretical considerations. In this case, in addition to the assumption that the nitrogen and oxygen molecules are diatomic molecules having three degrees of freedom in translation, two in rotation, we now must include another degree of freedom, namely, the vibration degree. The total energy is the sum of the individual energies obtained by solving Schrödinger's equation for each degree of freedom. The translational energy is found by treating the problem of a particle moving in a three-dimensional box with a potential energy in the box taken as zero. The rotational energy is obtained by treating the diatomic molecule as a three-dimensional rigid rotator whose equivalent mass is equal to the "reduced mass" of the molecule and the radius of rotation is equal to the equilibrium internuclear distance. Finally, the energy due to the vibrational degree of freedom is obtained by solving Schrödinger's equation where the potential function is taken as the potential function of the "reduced mass" of the diatomic molecule acting as a simple harmonic oscillator.

Once the total energy, the statistical weights, and the partition functions are known, then statistical thermodynamic equations can be used; and, after a series of proper mathematical manipulations, it can be shown that the equation for the specific heat at constant pressure as a function of the temperature for the case where the vibrational degree of freedom is included is

$$C_p(T) = 5997\left[1 + \frac{\gamma_p - 1}{\gamma_p}\left\{\frac{\left(\frac{\Theta}{T}\right)^2 e^{\Theta/T}}{\left(e^{\Theta/T} - 1\right)^2}\right\}\right] \tag{9}$$

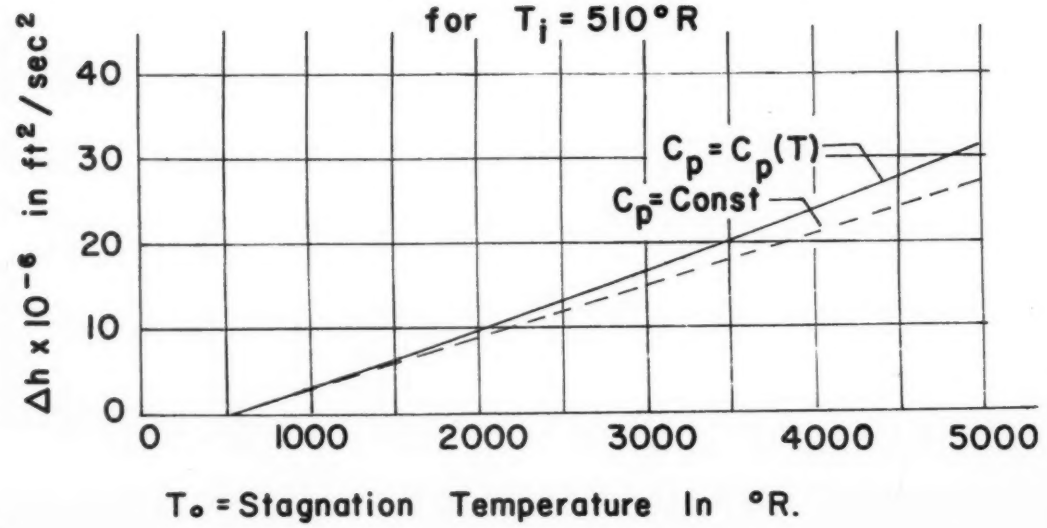
when $\Theta = 5500^{\circ}R$. Introducing Eq. (9) into Eq. (8) and then substituting this result along with Eq. (6) into Eq. (1) yields the power required to be

$$\frac{Q_r}{P_o A_*} = C_2\, f(T_o) \int_{T_i}^{T_o}\left[1 \frac{\gamma_p - 1}{\gamma_p}\left\{\frac{\left(\frac{\Theta}{T}\right)^2 e^{\Theta/T}}{\left(e^{\Theta/T} - 1\right)^2}\right\}\right] dT \tag{10}$$

where

$$C_2 \equiv \frac{1.356 \times 5.997}{\sqrt{R}}\left(\frac{2}{\gamma_p + 1}\right)^{\frac{\gamma_p + 1}{2(\gamma_p - 1)}}. \tag{11}$$

Fig. 2 - Enthalpy Change Across the Heater Versus the Stagnation Temperature for $T_i = 510^{\circ}R$



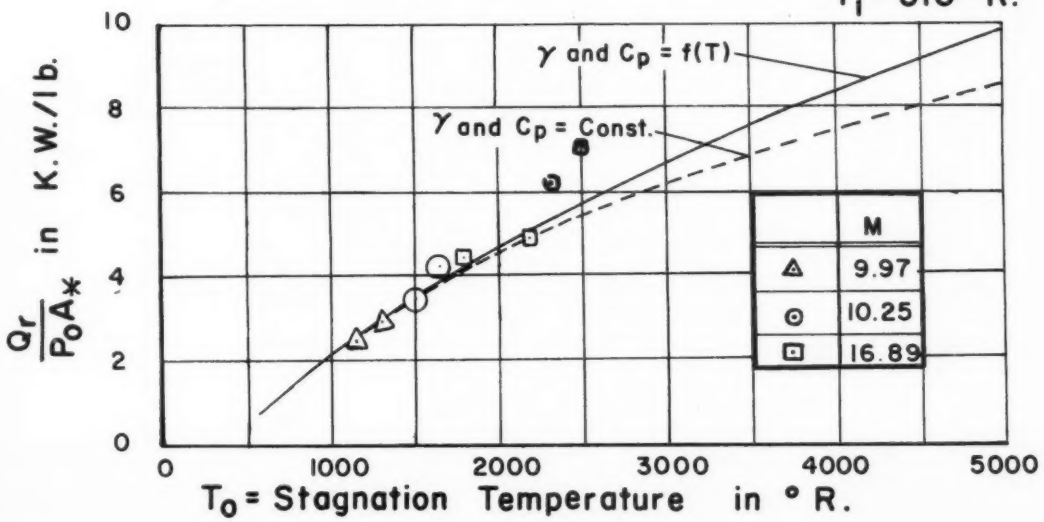
A plot of the change in enthalpy versus the stagnation temperature for a heater-inlet temperature of 510°R is shown in Figure 2 as a solid line. When Eq. (9) is substituted in Eq. (8), the function is nonlinear. This nonlinearity is the result of the vibrational degree of freedom in the diatomic molecule.

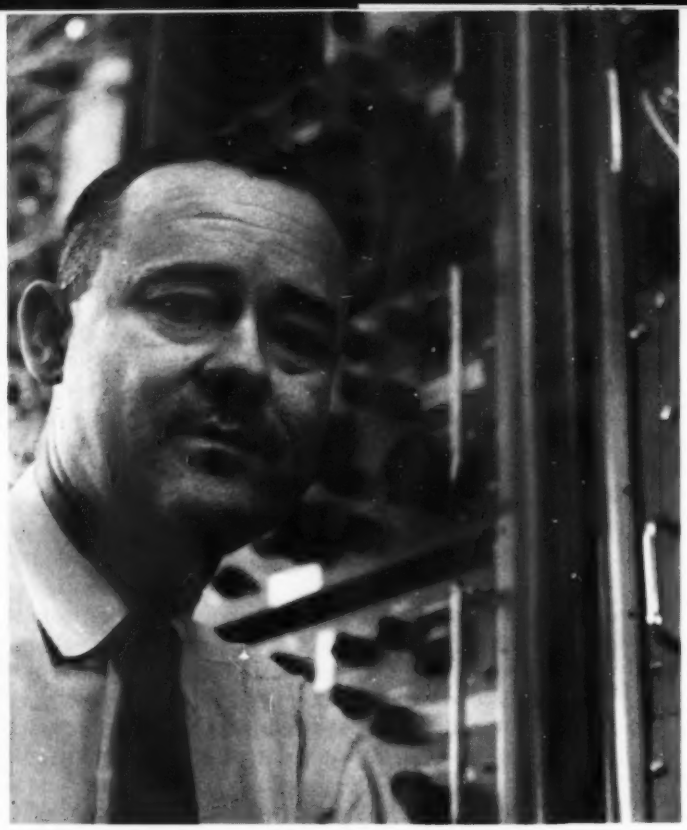
For a given stagnation temperature, the effect of the vibrational degree of freedom is to produce a greater value of the change in enthalpy across the heater.

A plot of $\dot{Q}_r/P_0A_*$ versus the stagnation temperature for a heater-inlet temperature of 510°R is shown in Figure 3. It should be noted that the power input increases with increasing stagnation temperature, stagnation pressure, and nozzle-throat cross-sectional area. For the case when the vibrational degree of freedom is neglected, the power equation is that given as Eq. (4). This equation is shown in Figure 3 as a dashed line. Assuming constant values of the nozzle-throat area and stagnation pressure, if the stagnation temperature is 1000°R, the difference in the power input between the two curves is insignificant. At higher stagnation temperatures, say 5000°R, it becomes obvious that a significant difference exists between the two methods and the vibrational degree of freedom must be considered in the power calculations. Also superimposed upon the curves on Figure 3 are experimental points obtained in the Aerospace Research Laboratories' 3- and 4-inch hypersonic wind tunnels. These data were obtained at Mach numbers of approximately 10 and 16.89. The scatter in the experimental data at the higher temperatures is due to the fact that the assumption of an adiabatic heater shell is violated. A simple calculation indicated that at a M = 16.89 and at stagnation conditions of P_0 = 1500 psia and T_0 = 2500°R approximately 1.9 kilowatts go into heating the shell of the 4-inch hypersonic wind tunnel; and, at the same conditions in the 3-inch hypersonic wind tunnel, as much as 5 kilowatts go into heating the pressure shell. This is due to the fact that the heater capsule for the 3-inch facility was designed for a much higher mass flow than that of the 4-inch hypersonic wind tunnel. In order to avoid structural problems due to the heating of the 3-inch facility shell, it was necessary to equip it with an air by-pass system. With the by-pass system in operation, the power input to the shell was reduced from 5 kilowatts to approximately 1.2 kilowatts.

More recent data taken at stagnation temperatures ranging up to 2500°R justifies the inclusion of the vibrational degree of freedom when computing heater-power input for hypersonic wind tunnels. ★

Fig. 3 – $Q_r / P_0 A_*$ Versus the Stagnation Temperature for T_i = 510 °R.





Between service as a member of a bomber crew in WW II and service in the Korean conflict, Mr. John P. Mullen was awarded the B.S. degree in Electrical Engineering from Northeastern University and later the M.S. degree from the same institution. His work has covered electronic countermeasures, computing systems, military-systems analysis, space electronics, arms control, radio astronomy, and satellite propagation studies. He has been a member of AFCRL since 1954, and is the author or coauthor of twelve publications in his fields of interest. He is a member of IEEE and RESA. Mr. Mullen is presently with the Radio Astronomy Branch of the Space Physics Laboratory (AFCRL).

In his responsibility as senior scientist for the ARL research program on hypervelocity and measurement techniques, Mr. Robert G. Dunn serves specifically as project scientist for aerospace simulation techniques. He has a B.S. degree in Chemical Engineering from Louisiana State University (1942) and an M.S. degree in Chemical Engineering from Ohio State University (1949). At present, he has completed all requirements, except his dissertation, for his Ph.D. degree in Chemical Engineering at Ohio State University. Mr. Dunn has several patents and a number of publications to his credit. In this Review, he writes on " 'Prohibition' for Wind-Tunnel Beds."

PROFILES

Dr. Robert Ruh, who writes in this issue of the Review on "Evidence for a New Crystal Phase of Zirconia," has been a research ceramist with ARL since 1955, investigating effects of metal additions to refractory oxides and determining phase relationships in metal-oxide and oxide-oxide systems. He has a B.S. in Ceramic Technology (1952), an M.S. in Ceramic Engineering (1953), and a Ph.D. in Ceramics (1960), all from Rutgers University. He also has written a number of publications. Currently, he is determining the phase relationships of the ZrO_2-Zr system, with emphasis on the ZrO_2 side.

As Chief of the Meteor Physics Branch, Space Physics Laboratory, AFCRL, Dr. Robert K. Soberman is continuing his extensive micrometeorite studies. He has written a number of publications in this area. Before coming to AFCRL in 1959, he was a research physicist with General Electric and a senior scientist at AVCO. He has a B.S. degree in Physics, Cum Laude (1950) from the City College of New York. Subsequently, he received his M.S. degree in 1952 and his Ph.D. degree in 1956. He belongs to several professional societies.

Mr. Robert A. Skrivanek is currently conducting research in the field of meteor physics. As a physical chemist in the Meteor Physics Branch, Space Physics Laboratory at AFCRL, his work is primarily concerned with the collection and study of extraterrestrial particles, captured by high-altitude probe rockets and satellites. He has worked as a chemical engineer with the Goodyear Tire and Rubber Company, and has served as an officer in the USAF. Mr. Skrivanek has a B.S. degree in chemical engineering from Lehigh University (1957) and is pursuing graduate studies in chemistry at the Northeastern University Evening Graduate School.

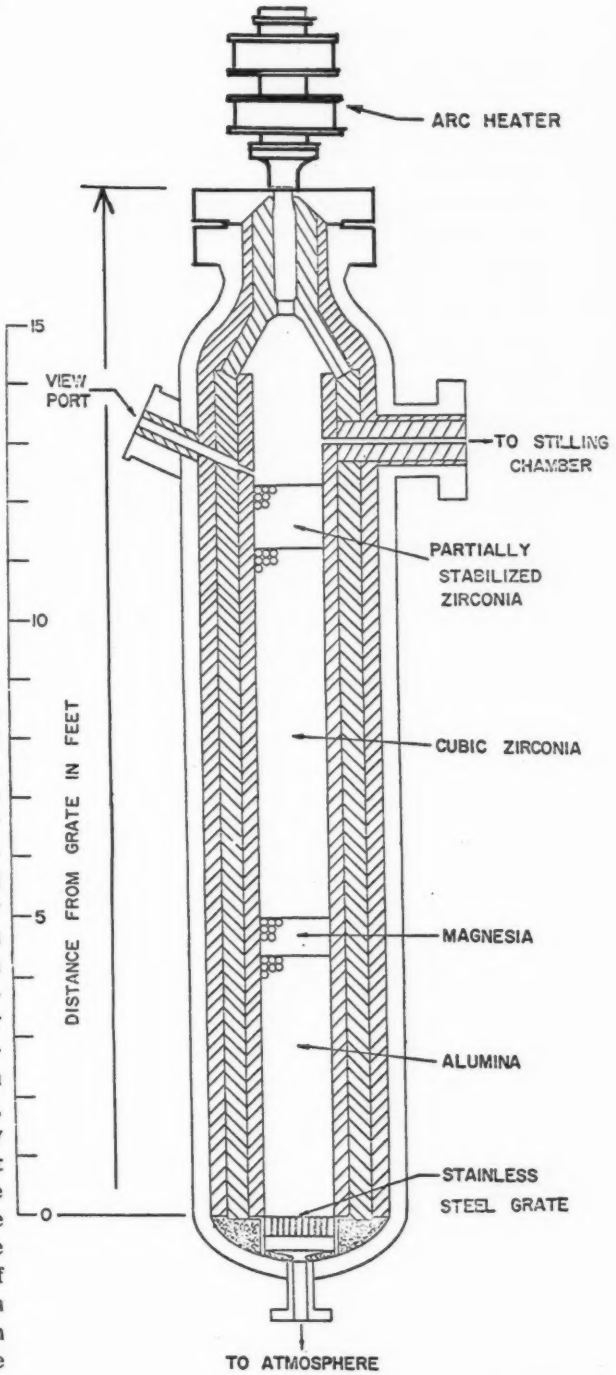
Dr. Hans E. Hinteregger is a senior scientist at AFCRL conducting an aerospace radiation research program in which AFCRL has assumed international prominence. He is presently Chief of the Solar Ultraviolet Branch, Upper Atmosphere Physics Laboratory, and represents AFCRL at international symposia and conferences. He is also permanent consultant to the NASA space program and is a member of the Rocket and Satellite Panel. Dr. Hinteregger has a "Diplom. Ingenieur" (Summa Cum Laude) 1944 and a "Dr. Techn." (Summa Cum Laude) 1947, both from the Vienna Institute of Technology, Vienna, Austria. He has received several Government honors and awards.

"prohibition" for wind-tunnel pebble beds

ROBERT G. DUNN
Fluid Dynamics Facilities Laboratory, ARL

An arc-heating technique for the preheating of hypersonic wind-tunnel pebble beds is being investigated with the objective of eliminating the serious problems inherent in the combustion heating method currently in use. Thus, it appears that at least one state "is going dry" in this election year--the state-of-the-art for hypersonic wind-tunnel pebble-bed heaters.

Long-duration hypersonic wind tunnels designed for operation at air-stagnation temperatures in the neighborhood of 4000°R are currently dependent on the pebble bed as a source of high-temperature air. ARL's 30-inch hypersonic wind tunnel is equipped with a typical zirconia pebble bed, which is currently preheated to temperatures up to 4400°R by combustion of natural gas, air and oxygen at atmospheric pressure. Experience with this pebble bed has revealed the fact that significant amounts of water vapor are trapped in the porous insulation ceramics during operation of the combustion burner. In the first wind-tunnel runs following the preheating period, this water vapor diffuses into the air stream, producing water-condensation shocks in the expansion region of the nozzle and, under certain conditions, furnishing nuclei which bring about early condensation of air components in the test section. Also, expansion of water condensate in cooler regions, when reheated, can be assumed to appreciably accelerate the ceramic-deterioration process. Further, if lean mixtures are used in the combustion process, nitric acid is formed, resulting in severe corrosion of all metal parts in the exhaust system; on the other hand, the use of rich mixtures produces combustion products deficient in oxygen, leading to reduction



ARC-HEATED PEBBLE-BED HEATER

of the zirconium-oxide ceramics and subsequent crumbling. Both effects are obviously detrimental to the life of the heater and related equipment.

To eliminate all of the aforementioned problems, a combined in-house and contractual program was initiated to provide an electrical arc heater which would replace the existing combustion heater. The basic design of the electric arc heater suitable for operation at atmospheric pressure was accomplished at the University of Michigan. The design of the housing for adaptation to the ARL 30-inch hypersonic wind-tunnel (HWT) pebble bed is under way. A transformer has been obtained from Government surplus and is being modified as required for operation of the arc heater. The arc unit is expected to be installed for tests on the 30-inch HWT pebble bed as soon as design and fabrication are completed and the transformer modified and installed. Experimental study of the limitations and problems related to this technique will be carried out during actual operation of the 30-inch HWT pebble bed. ★

studies OF THE THERMODYNAMICS OF ALLOY FORMATION

LAWRENCE R. BIDWELL, Metallurgy and Ceramics Research Laboratory, ARL

In recent years, the thermodynamics of alloy formation has received considerable attention. This has been the result of an increased realization that developments and improvements in the methods of producing useful metals and alloys stem most economically from the application of fundamental information about the reactions involved. Thermodynamic data on the reactions occurring in the formation of an alloy or compound, e.g., the energy changes and the transfer of heat that accompany the process, play a useful role in understanding the nature and the behavior of the alloy or compound in four principal ways: first, they provide information from which one can determine the effects of the atomic size and the magnetic, electronic, and electrochemical characteristics of the constituents on the resulting structure; second, they provide a means for predicting the alloy's behavior, such as its thermal stability and reactivity, in various physical and chemical environments; third, they are necessary for the quantitative treatment of such metallurgical processes as diffusion, nucleation, and transformation; and finally, in instances where data can be obtained for a range of compositions, they provide a quantitative basis for understanding and interpreting the phase equilibrium relationships of the system.

Although the science of thermodynamics has been widely applied to chemical problems for many years, its application to the field of metallurgy has been severely restricted until recently. This lag has been primarily due to the difficulties encountered in developing suitable high-temperature techniques for obtaining the necessary information. A new electrochemical technique that permits thermodynamic data to be obtained from metallurgical systems not amenable to study by previous methods is being exploited in the current investigations at ARL.[1] In this technique, solid calcia stabilized zirconia ($0.85\ ZrO_2 \cdot 0.15\ CaO$) is used as the electrolyte in a galvanic cell of the type

A, AO / electrolyte / A(B), AO.

One electrode contains metal A in equilibrium with its oxide AO while the other electrode contains A as one of the constituents of an alloy solid solution A(B) which is in equilibrium with the same oxide. It has been well established that, at temperatures in the range 650° to 1700°C (1202° to 3092°F), and at oxygen pressures greater than about 10^{-15} atm., the electrical conductivity of calcia stabilized zirconia is almost completely due to the transport of

oxygen ions. The contributions of electrons and of other ionic species to the conductivity are virtually nil. Consequently, the open-circuit potential of the above cell is related to the difference in the chemical potential of the oxygen in the two electrodes. If the solubility of oxygen in A is low and if the composition limits of AO are narrow, such that the chemical potential of AO in the two electrodes is essentially the same, then this difference is directly related to the chemical potential of A in the alloy, relative to pure metal A. All of the important thermodynamic properties related to the alloying process can be derived from an accurate knowledge of this quantity as a function of composition and temperature.

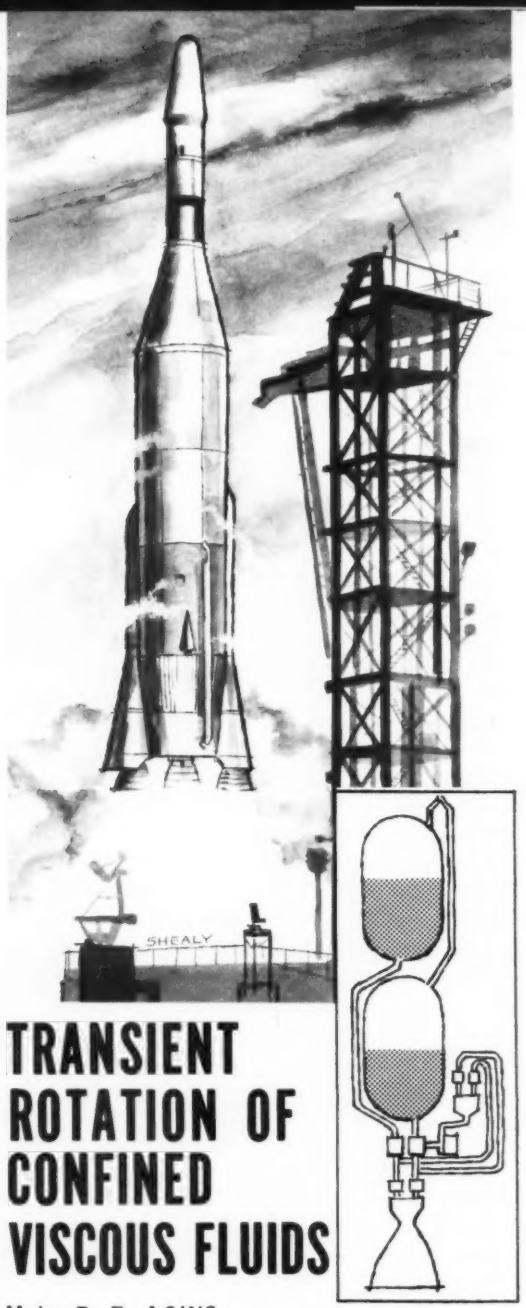
Using this method, an investigation of the thermodynamic properties of solid nickel-palladium alloys was undertaken in order to evaluate the degree to which they deviate from ideal solutions as a result of the difference in the atomic size and in the magnetic and electronic properties of pure nickel and palladium. Measurements of the chemical potential of nickel in a series of alloys covering the complete range of nickel-palladium compositions at temperatures from 700^{o} to 1200^{o}C (1292^{o} to 2192^{o}F) showed that the deviations from ideal-solution behavior were small but complex. It was observed that the deviations of the thermodynamic activities of nickel were positive in nickel-rich alloys and negative in palladium-rich alloys. On the other hand, the deviations of the palladium activities from ideality were negative for all compositions. The changes in enthalpy (heat content) on alloying were found to vary in a similar fashion. Thus, nickel-rich alloys are endothermic (heat absorbed) while palladium-rich alloys are exothermic (heat released). On the basis of a theoretical consideration of the probable magnetic, electronic, lattice-vibrational, and lattice-distortional contributions to the observed thermodynamic properties, it was concluded that nickel-palladium alloys, particularly those rich in palladium, exhibit a short-range ordering of the nickel and palladium atoms. In other words, the number of Ni-Pd bonds as compared to Ni-Ni and Pd-Pd bonds is larger than for the random case. Contrary to the recently published views of several Russian investigators, however, it was also concluded that the occurrence of a superstructure (long-range ordering of the nickel and palladium atoms) is unlikely. ★

[1] *Rapp, R. A., OAR Research Review, Vol. 1, Nr. 14, 24 September 1962.*

SCIENTIFIC notes

New High-Pressure Equipment: Delivered to AFCRL in April 1964 was a new, high-pressure, high-temperature press for the growth of crystals under high-pressure conditions. This new press is smaller than a similar press that has been in operation at AFCRL for several years but, like the larger press, has a tetrahedral design--that is, four cylinders are brought to bear on a pyramidal space containing the substance under investigation. As in the case of the existing apparatus, the new equipment will permit the growth of diamonds from carbonaceous material. The novel feature of the new press is that the transition from carbon to diamond can be monitored as it occurs by means of X-rays. It has not hitherto been possible to study this transition. (Solid State Sciences Laboratory, AFCRL)

AFCRL Report on Research: Published and available for general distribution is a 250-page report on the AFCRL research program and the recent progress made under the various AFCRL projects. The report is similar in format to one published last year by AFCRL and widely distributed to industry, universities and Government research laboratories. Only the unclassified portions of the AFCRL program are covered in the report, which is available for general distribution to all individuals and agencies having a need to become acquainted with this program. Requests for copies should be sent to: AFCRL (CRI), L. G. Hanscom Field, Bedford, Mass. 01731. (Research Information Office, AFCRL)



TRANSIENT ROTATION OF CONFINED VISCOUS FLUIDS

Major B. R. AGINS
Directorate of Mathematical Sciences, AFOSR

If a viscous fluid is in a container which is rotating, eventually the fluid will achieve the state of rotation of a solid body. If the angular velocity is changed, after a certain period of time, the fluid will again achieve solid-body rotation. But what is the motion between the time of disturbance and achievement of the steady-state condition? This question is important in such problem areas as: the dynamics of liquid propellant in rotating containers (missiles and launch vehicles), fluid gyroscopes and high-speed centrifuges.

A study was made of this problem by Professor H. P. Greenspan and L. N. Howard at the Massachusetts Institute of Technology, under sponsorship of AFOSR. The results were reported in a recent paper.*

They considered the manner in which the simplest state of rotary fluid motion of a viscous fluid, that of rigid rotation, is established. It was found that the transient motion consists of three distinct phases: the development of the Ekman layer; the inviscid fluid spin-up; and the viscous decay of residual oscillations. The Ekman layer plays the significant role in the transient process by introducing a small circulatory secondary flow. (The accumulation of tea leaves in the center of a stirred cup is a qualitative example of secondary flow). Low-angular-momentum fluid entering the layer from the geostrophic interior is replaced by fluid with greater angular momentum convected inward to conserve mass. The rotational velocity in the interior increases as a consequence of conservation of angular momentum, and the vorticity is increased through the stretching of vortex lines. The spin-up time is

$$T = \left(\frac{L^2}{\nu \Omega}\right)^{1/2}$$

where L is the characteristic dimension, parallel to the axis, of the container, Ω is the angular velocity about the axis, and ν is the kinematic viscosity.

Boundary-layer theory was used to study the phenomenon in the case of the general axially symmetric container configuration, and explicit formulas were deduced which exhibit the effect of geometry in spin-up. The special case of cylindrical side walls was also investigated by this method. Some very simple experiments confirmed the theoretical predictions. ★

*Greenspan, J. P. and L. N. Howard, "On a Time-Dependent Motion of a Rotating Fluid," J. of Fluid Mechanics, V. 17, Part 3, 1963.

discovering the invariant characteristics of things

CHARLTON M. WALTER
Data Sciences Laboratory, AFCRL

Dynamic data processing is a term that hasn't yet reached the familiarity threshold of many people. Essentially, it is a new approach to the use of the computer for data analysis. The high potential of the approach, coupled with encouraging progress made in recent months, demands closer inspection.

Data of all kinds--galactic noise picked up by a radiotelescope, psychological test scores or heart beats--are amenable to dynamic data processing. If we subject these data to analysis, we are likely to find certain invariant characteristics.

When we analyze data--manually, by conventional computer, or by dynamic data processing--we are looking for salient features, anomalies, invariants, and characteristic attributes. One distinctive aspect of the AFCRL study of analysis systems and techniques is that the computer itself can decide what features to look for. This offers a key departure from other approaches. Ordinarily, the investigator instructs the computer as to the features that should be analyzed. These judgments are naturally biased along the lines of the investigator's past experience, and the attributes uncovered may or may not be the most characteristic.

This is not to say that the investigator himself may not contribute worthwhile ideas to the analytical process. He can and, in the AFCRL study, he does participate in the process. He follows the progress of the analysis on a large colorscope. Interim results can suggest to him certain new areas to be explored. He can step in and make appropriate suggestions. A kind of dialogue relating to a common goal is thus possible between the investigator and the computer.

All of this offers the prospect of uncovering some rare and unexpected aspect of the data. Such a prospect by itself is an intriguing one from the purely research standpoint. Other potential benefits include the fast and economical analysis of research data--presently one of the most costly and time-consuming aspects of research. The processor can also handle degraded and noisy data from sensory inputs. Smaller and less sophisticated data-collection-and-transmission equipments can then be used, an important feature in the instrumentation of space probes. Sensory data (inputs from radars, communication links, radiotelescopes) can be processed on a real-time basis, or as the data are generated.

AFCRL's research is not centered on data analysis as such, but only on the design of data processors. The investigations involve a highly specialized equipment known as the DX-1 (an AFCRL designation). But the mathematical approach to the handling of data is one of the most novel aspects of the over-all program. AFCRL, together with a few others (notably W. H. Huggins of Johns Hopkins University), has adopted certain aspects of quantum theory. Behind this approach is the fact that for any signal there is an infinite set of data points. The uncertainties that limit the experimenter's ability to describe the data also limit his ability to predict the results of the measurements of the system. It is often impossible, because of the number of data points, the volume of data, the uncertain nature of the data, and the infinite set of associated variables, to arrive at a description through conventional computer mathematics and programming. Parameters for solutions to problems simply cannot be specified. For these reasons it is necessary to consider the data from the quantum statistical standpoint.

Research in dynamic data processing to date has opened several interesting philosophical considerations. One of these has to do with the act of data analysis itself and has given rise to the question as to whether or not, as in many experimental investigations of small-scale phenomena, the very act of observing and manipulating the data does not in some way change the data, thus compromising the validity or analysis. ★

"BRIDGING THE GAP" BETWEEN THEORY AND PRACTICE IN CONTROL THEORY

Major BERNARD S. MORGAN, JR.
Directorate of Mathematical Sciences, AFOSR

The purpose of this short article is to present some of the highlights of the discussion of a problem common to many sciences. That is, "How does one bridge the gap between theory and practice?" The problem as it pertains to control theory and automation was considered at a recent special meeting of the American Automatic Control Council (AACC), which is a committee of delegates representing the following professional societies: American Institute for Aeronautics and Astronautics; American Institute of Chemical Engineers; American Society of Mechanical Engineers; Instrument Society of America; and Institute of Electrical and Electronic Engineers (IEEE). AACC is a member of the International Federation of Automatic Control whose objectives are to facilitate the interchange of information in automatic control, to promote progress in this field, and to organize international congresses in automatic control.

Three gaps were immediately pinpointed. The first gap exists between universities (those who generate the theory) and the industrial suppliers of hardware for automation (those who use the theory). The second exists between the suppliers and the users of the hardware. The latter are the managements which make the decisions to automate. The third exists between universities and the users.

The first gap is the result of the recent advances in the mathematical aspects of control theory. These recent advances, coupled with a revolution in engineering education and its accompanying emphasis on mathematics and science, have tended to decrease the ability of the recent engineering graduates to communicate with the practicing engineer in industry.

The second gap is of an economic and educational nature. The suppliers of hardware must be able to show to the users that considerable money can be saved by applying new theories to design. It is interesting to note that, in certain industries, it has been easier to sell such ideas (use of control or automation) to non-English-speaking nations than to the English-speaking ones. It has been surmised that one reason for this might be the greater technical education of the upper management of the non-English-speaking nations.

The third gap is caused by the neglect of the universities to educate management on what control theory and automation are all about. This gap could be bridged by a greater use of short courses on the modern theory of control and its implications.

Only the first gap was considered in detail, and many recommendations were made as to how to help bridge this gap. Some of these are: (a) a yearly publication of state-of-the-art and tutorial papers which include an explanation of the application of theory to practical problems, and an enumeration of the practical problems for the theory to be developed (the AF Flight Dynamics Laboratory's support of a critical review of the automatic-control literature[1] by the Polytechnic Institute of Brooklyn was cited by the group as an excellent start on this; it also plans to support, on a small scale, state-of-the-art reports); (b) the formation of an industry-oriented practical graduate program leading to doctorates in engineering; (c) greater interchange of university and industry people so that each can learn the problems of the other; (d) encouragement of research programs which evaluate the relative merits of the application of theories of control to real-life problems such as in the design of a specific aerospace vehicle-

control system (this has also been done on a small scale by the AF Flight Dynamics Laboratory); (e) finally, specific examples of the application of theory to practical problems should be determined and publicized.

The details of the discussion and all the recommendations will appear in a report[2] to be published in either the Transactions of Automatic Control or the Spectrum of the IEEE.

1. *Dorato, P., "A Selected Bibliography and Summary of Articles on Automatic Control - March 1962 through December 1962, Vol. 1," Research Report PIBMRI - 1106-62.*

2. *Chestnut, H., Report of Joint Meeting of AACC Theory and Applications Committees, "Bridging the Gap Between Theory and Practice," 27 Mar. 1964.*

PRECURSOR ARCS in ELECTRIC SHOCK TUBES

Dr. ROBERT F. STETSON, Directorate of Physical Sciences, AFOSR

In a paper recently submitted to the Physics of Fluids, Professor John Barach of Vanderbilt University described his observations of precursor arcs in an electric shock tube. An electric shock tube is commonly used in plasma physics since it is a relatively inexpensive means of producing an ionized gas. Its business end consists of a capacitor bank which is first charged to a high potential after which the energy is dumped into the gas. The gas is thus ionized and heated in the process and, since the energy is usually dumped into a small volume of gas confined by rigid walls, a shock wave results. The shock wave typically travels down a tube where its effects may be studied and correlated with the characteristics of the energy pulse used to create the pressure pulse.

Professor Barach uses a discharge circuit whose half period is ~70 microseconds, and dumps the energy into argon at initial pressures of from 0.15 to 5.0 Torr.* The light output from the tube is monitored by a photomultiplier which looks at either a pair of aluminum lines emitted by the electrode material or at the Hβ line, present because of the small amounts of hydrogen found as an impurity in the argon. Currents in the shock tube are monitored by means of a single wire probe and by a set of pickup coils which provide the input to an oscilloscope. One of the interesting points of Barach's work is that he finds an arc of some hundreds of amperes preceding the shock front and running from the discharge circuit to the same grounded probe previously mentioned as a detector. The arc can extend quite far downstream in the discharge, and is still of the order of several amperes even with the probe separated from ground by 5 ohms. According to Barach, such precursor arcs may run to grounded points (such as electrodes and diffusion pumps) and cause ambiguous experimental results such as the appearance of a double structure to the shock front. The precursor arc may also serve a useful purpose by increasing shock velocities as it heats the gas immediately in front of the shock, or as a means of producing electron densities $\sim 10^{14}/cm^3$ in electric shock tubes. Both the latter effects will be used as a starting point for further research.

Professor Barach's work, which was supported by AFOSR Grant No. 287-63, is of interest from another point of view. It demonstrates that stimulating and important research can still be done by a grantee who is supported essentially as a one-man-show, is aided by a few graduate and undergraduate students, operates on a comparatively small budget, and works in a nineteenth-century building. Such accomplishments are really not so unusual; but, in light of the current trend toward multiinvestigator, multipostdoctoral, multimegabucks, and multitechnician programs operated in shiny new buildings with the very latest in research equipment, it is an approach to research which can be overlooked too easily. ★

**Named after Torricelli - one Torr = a pressure that will support a column of mercury 1 millimeter high.*

when is a mathematician a mathematician?

Captain JOHN F. GANDER
Directorate of Mathematical Sciences, AFOSR

Appropriately, the answer one must give to such a question is: "When he is doing mathematics." Unfortunately, this answer leads us to another question for which it is equally difficult to find a suitable answer. However, to continue the cyclic chain, we should quote a description of mathematics as a whole which could be seriously considered as a likely candidate. It is the much-quoted epigram which Bertrand Russell pronounced in 1901: "Mathematics may be defined as the subject in which we never know what we are talking about, nor whether what we are saying is true." Just what one would expect from B. Russell.

At this point a slight pause is in order, for certainly such a definition has jarred our common sense. Is this so terrible? Surely common sense can afford the competition of uncommon sense at times. This is one of the services which mathematics has rendered mankind, i.e., "putting common sense where it belongs" on the shelf next to "discarded nonsense." But this definition has more to it than meets the eye. It emphasizes the completely abstract character of mathematics. It also suggests the postulational form that mathematics is now taking. Finally, it shatters the traditional dictionary ("layman" should also be included) definition of mathematics (much to the liking of mathematicians) as the science of number, quantity and measurement. Here we are not saying that these things are not an important part of the material to which mathematics has been applied; but they are not mathematics, nor are their users mathematicians.

But then, when is a mathematician a mathematician? Again we say: "When he is doing mathematics." Here we can get a glimpse of the direction in which we are headed if one admits the unfortunate fact about mathematics, that is, that it requires us to reason, and it is not clear to most humans that reasoning is worthwhile. Indeed, reasoning in general, and mathematical reasoning in particular, are of questionable value. However, one must be made to realize that, in mathematics, reasoning is the sum and the substance, and what the reasoning yields is desirable knowledge, the purpose of all reasoning. Perhaps a few examples will clear the air and give an answer to our question.

First, consider a simple example. Suppose that a young secretary has a choice between two jobs. Each has a starting salary of $4000 per year; but the first one would lead to an annual raise of $200, whereas the second would lead to a semiannual raise of $50. Which job is preferable? Perhaps a little mathematical reasoning (left as an exercise for the reader) will convince one that the obvious answer is not the right one.

Now let us consider a real example of how a mathematician does mathematics. Results of work by Professor Y. Takahashi on the structure of the nucleon core by the Hartree approximation lead to a particular partial differential equation

$$\Delta x = x + x^2 \qquad (1)$$

Physical considerations suggested that the equation

$$\frac{d^2 x}{dt^2} + \frac{2dx}{tdt} = x + x^2 \qquad (2)$$

may be expected to possess a desired solution. Under the assumption that such a solution existed, Professor Synge developed an ingenious method for the numerical computation of a solution. However, the question of the existence of such a solution was left open.

Now we see when a mathematician is a mathematician. Professor Zeev Nehari, working under a mathematics grant from AFOSR, presented the much-needed existence proof. Of interest here to our main topic of discussion is the way in which this mathematician set about to do the job. Professor Nehari's first step (one of the marks of a true mathematician) was to generalize the problem to include a much wider range of equations than that covered by equation (2). Then, with a flash of mathematical intuition, he saw that the calculus of variation could be put to use. He set up a variational problem for the new general class of equations under the particular conditions imposed by the physical considerations. The existence of the solution of the variational problem was then handled by a direct method.

The next step was to establish the convergence of the sequence of functions obtained in the variational approach to the problem. This was done by the construction of comparison functions and the use of Ascoli' lemma. The final touch to the proof was to show that the convergent subsequence obtained gave the desired results for the particular physical considerations.

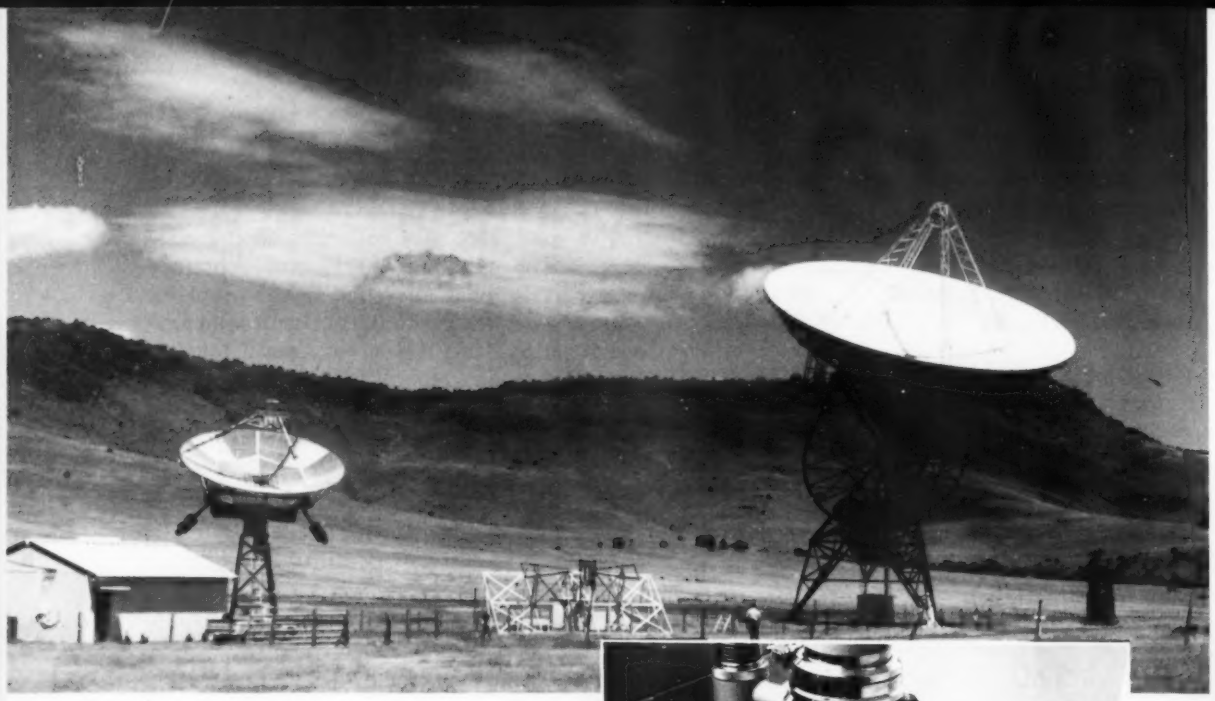
The paper* of Professor Nehari also shows how the procedure of the existence proof can be converted into a procedure for the numerical computation of the desired function. The details are of course much too complicated to go into here.

Now, to complete the chain, we see clearly that a mathematician is a mathematician "when he is doing mathematics." ★

*Nehari, Zeev, "On a Nonlinear Differential Equation Arising in Nuclear Physics," Proc. Royal Irish Acad., 62, Sec. A, No. 9, 1963.

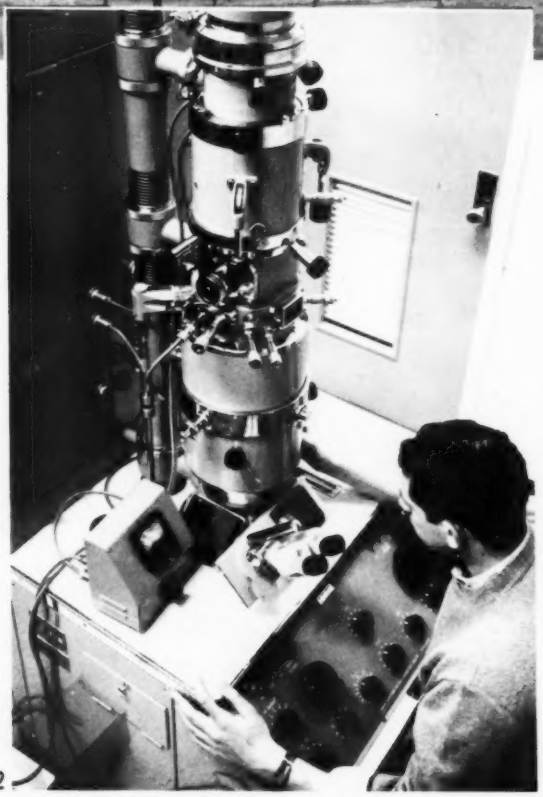
NEW USAF EQUIPMENT AT U. of BARCELONA

Two associates of Dr. Manuel Ballester, Professor of Organic Chemistry at the University of Barcelona, Spain, check out a Perkin-Elmer Model 350 Ultraviolet Spectrophotometer recently delivered there. This new piece of U. S. Air Force equipment is on loan to Dr. Ballester's laboratory from the European Office, OAR.



1

AFCRL TOOLS FOR RESEARCH



2

Photo 1 *A little-known radio observatory is the one located at Ft. Davis, Texas. This facility, operated by the Harvard College Observatory, is used in support of AFCRL research at the Sacramento Peak Observatory, Sunspot, New Mexico.*

Photo 2 *Electron microscopy is a powerful tool for examining the details of single crystals and for analyzing crystal composition. Such equipment is extensively used by AFCRL scientists analyzing the properties of novel crystals grown at AFCRL.*

OAR (RRYC)
BLDG T-D
WASH DC 20333

UNITED STATES AIR FORCE
OFFICIAL BUSINESS

POSTAGE AND FEES PAID
DEPARTMENT OF THE AIR FORCE

OAR (RRYC)
BLDG T-D
WASH DC 20333

research review
OFFICE OF AEROSPACE RESEARCH

NEW APPLICATION

(NOT TO BE USED BY A CURRENT READER)
No postage required if mailed in the United States.

PLEASE PRINT

NAME _____

COMPANY _____

DIVISION _____

COMPANY ADDRESS _____

CITY _____ STATE _____ ZIP CODE _____

ADDRESS COPIES TO ☐ ABOVE ☐ HOME (BELOW)

(Company Name and Division MUST Be Included Even If Copies Are Sent To Home Address)

HOME ADDRESS _____

CITY _____ STATE _____ ZIP CODE _____

to our readers

Requests for further information should be directed to the individual or laboratory of origin (except for those from Latin America).

Addresses are as follows:

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
Attn: CRI
Laurence G. Hanscom Field, Bedford, Massachusetts 01731

AEROSPACE RESEARCH LABORATORIES
Attn: ARB
Wright-Patterson Air Force Base, Ohio 45433

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
Attn: SRGL
Tempo D Building
4th and Independence Avenue, S.W., Washington, D.C. 20333

OFFICE OF RESEARCH ANALYSES
Attn: ORR
Holloman AF Base, New Mexico 88330

Requests for further information from institutions and individuals in Latin America should be addressed to:

LATIN AMERICAN OFFICE AEROSPACE RESEARCH
U. S. EMBASSY
Rio de Janeiro, Brazil

Detailed documentary reports may be obtained from:

OFFICE OF TECHNICAL SERVICES
U.S. Department of Commerce, Washington, D.C. 20230

DEFENSE DOCUMENTATION CENTER FOR SCIENTIFIC AND TECHNICAL INFORMATION*
Cameron Station, Alexandria, Virginia 22314

* Qualified requestors